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16. ABSTRACT On March 20, 1984 the U. S. Environmental Protection Agency proposed revisions to the national ambient air quality standards (NAAQS) for particulate matter. New primary standards were proposed for particulate matter measured as PM₁₀ (particles with aerodynamic diameters equal to or less than a nominal 10 μm). In addition to the revisions to the NAAQS's, EPA also proposed a new Federal Reference Method (FRM) for the measurement of PM₁₀ in the atmosphere and appropriate revisions to the EPA regulations concerning Ambient Air Monitoring Reference and Equivalent Methods and Ambient Air Quality Surveillance. The proposed FRM for PM₁₀ is based on discrimination and selection of PM₁₀ particles by inertial separation in a specially shaped inlet, followed by conventional filtration of a measured volume of sampled air and determination of the net weight gain of the filter. Wherever feasible, sampler requirements are prescribed by functional or performance specifications to allow maximum flexibility in the design or configuration of PM₁₀ samplers. Candidate samplers would have to be tested according to explicit test procedures and formally designated as reference or equivalent methods. This paper will review the proposed NAAQ's and related monitoring requirements and discuss EPA's PM₁₀ sampler development and evaluation activities.		
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USEPA PM₁₀ METHODOLOGY REVIEW

by
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INTRODUCTION

As a result of its re-evaluation of the health and welfare criteria for particulate matter, the United States Environmental Protection Agency (USEPA) proposed, on March 20, 1984, the following revisions to the National Ambient Air Quality Standards (NAAQS) for particulate matter [1]:

1. That the measurement of Total Suspended Particulate Matter (TSP) as an indicator for ambient concentrations of particulate matter be replaced for both of the primary standards by a new indicator that includes only those particles with an aerodynamic diameter smaller than or equal to a nominal 10 micrometers (PM₁₀);
2. That the level of the 24-hour primary standard be changed to a value to be selected from a range of 150 to 250 $\mu\text{g}/\text{m}^3$ and that the current deterministic form of the standard be replaced with a statistical form that permits no more than one expected exceedance of the standard level per year;
3. That the level and form of the annual primary standard be changed to a value to be selected from a range of 50 to 65 $\mu\text{g}/\text{m}^3$ and the form be expressed as an expected annual arithmetic mean; and
4. That the current 24-hour secondary TSP standard be replaced by an annual TSP secondary standard to be selected from a range of 70 to 90 $\mu\text{g}/\text{m}^3$, expected annual arithmetic mean.

The existing primary and secondary standards for TSP and these proposed new standards for PM₁₀ are shown in Table I.

The March 20, 1984 proposal involves amendments to Title 40 - Protection of the Environment of the Code of Federal Regulations (40 CFR), which contains all general and permanent rules published in the Federal Register by the USEPA. In addition to the revisions to the NAAQS, which are codified in 40 CFR Part 50, the USEPA also proposed a new Federal Reference Method (FRM) for the measurement of PM₁₀ in the ambient air (new Appendix J of (40 CFR Part 50) and appropriate revisions to the regulations concerning Ambient Air Monitoring Reference and Equivalent Methods (40 CFR Part 53) and Ambient Air Quality Surveillance (40 CFR Part 58). This presentation will focus primarily on the new FRM and on the revisions to the reference and equivalent method regulations.

NEW PM₁₀ REFERENCE METHOD

The current appendixes to 40 CFR Part 50 describe requirements for reference methods to be used for measuring each of the pollutants for which an NAAQS has been established. For each pollutant, a corresponding appendix specifies either a complete, unique, manual reference method (e.g., TSP, SO₂, Pb) or a measurement principle and calibration procedure applicable to automated reference methods, which must also meet performance requirements specified in 40 CFR Part 53 (e.g., CO, O₃, NO₂).

The new Appendix J, proposed to be added to Part 50, describes the reference method for PM₁₀. Appendix J deviates somewhat from the scheme established for TSP (Appendix B) in that the method described is considered a manual method even though the requirements resemble the

measurement principle and performance requirements normally prescribed for automated methods. This approach was taken to provide for greater flexibility, to allow for the use of various currently available particulate matter samplers, and to encourage continuing improvements and innovative new sampler designs.

The proposed reference method for PM_{10} is based on discrimination and selection of PM_{10} particles by inertial separation in a specially shaped inlet, followed by conventional filtration of a measured volume of sampled air and determination of the net weight gain of the filter. The sampler (or sampler inlet) would be required to meet performance specifications and would have to be tested according to the explicit test procedures prescribed in 40 CFR Part 53, which are discussed in detail in the following section. Methods for PM_{10} that meet all requirements would be designated as PM_{10} reference methods and would be identified, in most cases, by the manufacturer and model of the sampler. Wherever feasible, the requirements in Appendix J are prescribed as functional or performance specifications rather than design specifications to allow maximum flexibility in designing or configuring PM_{10} samplers. Sampler shape, inlet geometry, filter material and size, operational flow rate, degree of automation, and so forth are all specified in terms of required function or performance.

Accordingly, the proposed reference method prescribes no specific flow rate of PM_{10} samplers. High flow rate samplers, such as the existing high-volume samplers equipped with a size-selective inlet, would be approved if they meet all of the performance requirements. Medium and low flow samplers would also be allowed, provided enough mass

is collected to meet a reproducibility specification. PM₁₀ samplers would have to be designed to minimize measurement errors resulting from filter handling operations such as conditioning, weighing, and installation on and removal from samplers.

An alkalinity specification is included that would disallow the use of excessively alkaline filter media, which could lead to possible measurement errors from artifact formation. Filters meeting this specification should show little or no sulfate artifact but may be subject to errors due to nitrate artifact. However, for most sampling locations, PM₁₀ mass concentration errors due to positive nitrate artifact or loss of nitrate by volatilization or chemical reaction are expected to be small. The proposed filter specifications are intended to be minimum requirements when measurement of PM₁₀ mass concentration is of primary concern. Users would need to consider additional filter requirements if other sampling objectives were to be met.

PM₁₀ samplers would be required to have the capability of collecting valid samples at ambient concentration levels consistent with the proposed NAAQS. A filter's capability of withstanding high particle mass loadings is an important concern. Ideally, the pressure drop across the filter should be sufficiently low to minimize the potential for overloading. To further minimize this possibility, samplers should have the capability of maintaining normal flow rates over as wide a range of pressure drop as is practical. Sampler manufacturers have been encouraged to consider the potential for filter overloading in designing their samplers and in selecting their recommended filter media. Samplers that incorporate automatic

filter-changing mechanisms to switch from a particle-loaded filter to a fresh filter during the 24-hour sample period would be allowed, provided the reproducibility of the PM_{10} measurement met the required specification.

Sampler manufacturers would be required to provide sampler purchasers with an operation or instruction manual containing detailed procedures for calibration and operation of the sampler, as well as recommendations regarding appropriate filter media and type of analytical balance required for mass determinations. Such a manual would be required by 40 CFR Part 53, which would require submission of the manual as part of the manufacturer's application for a reference method determination.

PERFORMANCE REQUIREMENTS FOR PM_{10} SAMPLERS

Regulations in 40 CFR Part 53 provide for the determination and designation of reference and equivalent methods. The principal change proposed to Part 53 is the addition of a new Subpart D, which prescribes performance specifications and test procedures specifically applicable to candidate methods for PM_{10} . Specifications and associated test procedures have been proposed in Subpart D for sampling effectiveness (for both liquid and solid particles), 50 percent cutpoint, reproducibility, and flow rate stability.

The performance specifications proposed for PM_{10} candidate methods are shown in Table II. Sampling effectiveness refers to the portion (percent) of particulate matter collected (collection efficiency) at a specific particle size (aerodynamic diameter). PM_{10} samplers normally have a smooth, S-shaped sampling effectiveness curve dropping from near

100% to near 0% as the particle size increases from 1 to 50 micrometers (μm). The 50 percent cutpoint is the particle size (point on the sampling effectiveness curve) at which the sampling effectiveness is 50 percent. The proposed 50 percent cutpoint has been established at $10 \pm 1 \mu\text{m}$. The acceptability of the sampling effectiveness of a candidate PM_{10} sampler would be tested by comparing it to the sampling effectiveness of a specified "ideal" sampler.

A candidate PM_{10} sampler would be required to produce an expected PM_{10} mass concentration measurement within $\pm 10\%$ of the expected PM_{10} mass concentration calculated for the ideal sampler, assuming a specified typical ambient particle distribution. The model for the ideal sampler is designed to approximate particle penetration to the thoracic region of the human respiratory tract, and was obtained from a regression equation for extrathoracic deposition of particles in the human respiratory tract during mouth breathing [2]. When this regression equation is transformed into a thoracic penetration equation, a model for the sampling effectiveness curve for the ideal sampler is obtained.

An expected mass concentration is calculated for the ideal sampler by integrating the product of the sampling effectiveness curve for the ideal sampler and a typical ambient particle distribution. The mass distribution data of Lundgren and Paulus [3] for a typical urban atmosphere is used to specify the ambient particle distribution. The integration of the product of the ideal sampler's effectiveness curve (or function) and the typical ambient particle mass distribution results in a calculated mass concentration of $52.3 \mu\text{g}/\text{m}^3$ for the ideal sampler.

The tests for sampling effectiveness of a candidate PM_{10} sampler would be conducted in a wind tunnel test facility. Replicate measurements of liquid particle sampling effectiveness for the five particle sizes and three wind speeds shown in Table III would be required. These test data would then be used to plot the sampling effectiveness curve for the candidate sampler (or sampler inlet) at each of the three wind speeds. As with the ideal sampler, integration of the product of the sampling effectiveness curve for the candidate sampler and the ambient particle distribution yields an expected mass concentration for the candidate method. To pass the liquid particle sampling effectiveness test, the expected mass concentration for the test sampler (for all three wind speeds) would have to be within $\pm 10\%$ of that predicted for the ideal sampler. The 50 percent cutpoint of the test sampler is determined from the liquid particle sampling effectiveness curves and would have to be $10 \pm 1 \mu m$ at each of the three wind speeds.

A test for solid particle sampling effectiveness would also be required to demonstrate that bouncy particles larger than $10 \mu m$ are not unintentionally collected by candidate PM_{10} samplers. The test would be conducted in a wind tunnel using $20 \mu m$ particles and wind speeds of 8 and 24 km/hr . Performance of a candidate PM_{10} sampler would be acceptable if the sampling effectiveness for solid particles is no more than five percent (absolute sampling effectiveness) above that obtained for liquid particles of the same size.

The reproducibility and flow rate stability of a candidate method would be tested on three identical PM_{10} samplers simultaneously

sampling ambient air for five sample periods of 24 hours each. For each of the five sets of PM_{10} concentration measurements, the reproducibility is calculated as the coefficient of variation and would have to be 15 percent or less to be acceptable. To determine flow rate stability, the flow rate of each test sampler would be recorded at the beginning and end of each 24-hour sampler period. For performance to be acceptable, the percent difference between the initial and final flow rates would have to be within $\pm 10\%$ of the initial flow rate for each of the test samplers and sample periods.

The proposed amendments to Part 53 also allow designation of equivalent methods for PM_{10} based on measurement principles different from the principle described for PM_{10} reference methods in Part 50. Candidate equivalent methods for PM_{10} would have to meet the performance requirements of Subpart D as described above, as well as new comparability requirements for PM_{10} methods proposed to be added to Subpart C, which prescribes procedures for determining comparability between candidate equivalent methods and reference methods. The collection of five sets of simultaneous 24-hour PM_{10} samples with a reference method sampler and with three candidate method samplers at each of three different test sites would be required for determining comparability of candidate equivalent methods to a reference method. These samples would be analyzed by the reference or candidate method, as appropriate, to obtain the corresponding PM_{10} measurements. For each candidate method measurement, the percent difference between the measurement and the corresponding reference method measurement would be calculated and compared to the allowable specification. No more than

one difference per test site would be allowed to exceed $\pm 20\%$ of the corresponding reference method measurement to pass the comparability test. The three test sites would have to be located in geographical areas having particulate matter of differing character or composition so that the test sampler would be tested under a variety of particulate matter conditions.

PM₁₀ DEVELOPMENT AND EVALUATION ACTIVITIES

Over the past several years the USEPA has been actively conducting a particulate sampler development and evaluation program. Essentially all of the inlets for the current commercially available PM₁₀ samplers have been developed and extensively evaluated under cooperative agreements between USEPA and several independent aerosol researchers. Recent activities have focused on the proposed approach for determining the acceptability of PM₁₀ samplers, including detailed evaluation of critical FRM parameters, performance specifications and test procedures, and field investigations of current PM₁₀ samplers. A USEPA wind tunnel test facility has been fabricated and put into operation at Research Triangle Park, NC for evaluating the proposed FRM performance test procedures and conducting PM₁₀ sampler performance tests. An interlaboratory comparison of two PM₁₀ inlets in three different wind tunnels [4] and a field comparison of several PM₁₀ samplers at four locations [5] has been conducted. A brief description of these two studies follows.

In order to examine the variability of PM₁₀ inlet performance test data from different wind tunnel testing facilities, an interlaboratory study of two similar dichotomous sampler PM₁₀ inlets was undertaken.

Each of the three participating laboratories tested the inlets in separate wind tunnels at 8 km/hr with liquid particles. The results, summarized in Table IV, indicate reasonable agreement between the laboratories. This study was a first attempt at an interlaboratory evaluation of PM₁₀ inlets and considering that the study was conducted without standardized test procedures and prior to the proposal of the FRM performance test requirements, the results were encouraging.

A comprehensive field study was conducted to compare the performance of several commercially available PM₁₀ inlets under a variety of field conditions. Inlets for low, medium, and high flow samplers were compared at four sampling locations, selected to provide a wide range of concentrations and particle sizes. The study was designed to estimate precision, determine relative biases between inlet types, determine daily total mass distributions by particle size, and compare measured concentrations to computed values based on the mass distribution and available wind tunnel inlet characterization data. Daily distributions of mass by aerodynamic diameter were measured using a Wide Range Aerosol Classifier and the composited data were reported. Expected mass concentrations for each sampler were calculated using the sampler effectiveness data and the size distributions and then compared to the measured values.

The results of this study indicate that the precision of the PM₁₀ samplers is well within the FRM requirements. The performance of the inlets as characterized by wind tunnel testing provided computed results which in most cases were within $\pm 10\%$ of the measured values. A variety of sampling and operational problems were identified and corrective

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actions were initiated. The overall objective of evaluating available PM₁₀ hardware in light of the proposed FRM requirements was accomplished.

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Table I. Air Quality Standards for Particulate Matter

Existing Standards (TSP)

Primary Standard:

24-hour - 260 $\mu\text{g}/\text{m}^3$
Annual - 75 $\mu\text{g}/\text{m}^3$

Secondary Standard:

24-hour - 150 $\mu\text{g}/\text{m}^3$
Annual - 60 $\mu\text{g}/\text{m}^3$

Proposed New Primary Standard (PM_{10})

24-hour - a value to be selected from the range,
150 to 250 $\mu\text{g}/\text{m}^3$

Annual - a value to be selected from the range,
50 to 65 $\mu\text{g}/\text{m}^3$

Proposed New Secondary Standard (TSP)

Annual - a value to be selected from the range,
70 to 90 $\mu\text{g}/\text{m}^3$

Table II. Performance Specifications for PM₁₀ Samplers

Performance parameter	Units	Specification
1. Sampling effectiveness	%	
A. Liquid particles		Expected mass concentrations calculated from the sampling effectiveness curves for all 3 wind speeds must be within $\pm 10\%$ of that calculated for the ideal sampler.
B. Solid particles		Sampling effectiveness must be no more than 5% above that obtained for liquid particles of same size.
2. 50 percent cutpoint	μm	$10 \pm 1 \mu\text{m}$ aerodynamic diameter.
3. Reproducibility	%	15% coefficient of variation for 3 collocated samplers.
4. Flow rate stability	%	Within $\pm 10\%$ of initial flow rate over 24 hours.

Table III. Particle Sizes and Wind Speeds for
Sampling Effectiveness Tests

Particle size (μm) ^a	Wind Speed (km/hr)		
	2	8	24
5 $\pm$ 0.5	l	l	l
7 $\pm$ 0.5	l	l	l
10 $\pm$ 0.5	l	l	l
14 $\pm$ 1.0	l	l	l
20 $\pm$ 1.0	l	l/s	l/s

^aMass median aerodynamic diameter

l = liquid particle

s = solid particle

Number of liquid particle test points (minimum of 3 replicates
for each combination of wind speed and particle size): 45

Number of solid particle tests (minimum of 3 replicates): 6

Total number of test points: 51

Table IV. Summary of Sampling Effectiveness Statistics
Based on Lognormal Approximations

	TAMU		RTI		FAME	
	$D_{50}, \mu\text{m}^a$	σ_g^b	$D_{50}, \mu\text{m}^a$	σ_g^b	$D_{50}, \mu\text{m}^a$	σ_g^b
Inlet 1	11.9	1.49	11.3	1.56	11.0	1.26
Inlet 2	11.9	1.51	10.5	1.50	11.4	1.27

^a Diameter corresponding to 50% sampling effectiveness taken from empirical curves.

^b $\sigma_g = (D_{16}/D_{84})^{1/2}$. Diameters corresponding to 16% and 84% sampling effectiveness from the empirical curve.